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Review Article

The Effects of Superabsorbent Polymers on Soils and Plants

D. Khodadadi Dehkordi

Department of Water Engineering and Sciences, Ahvaz Branch, Islamic Azad University, Ahvaz, Iran

ABSTRACT

Current climate change is projected to have significant effects on temperature and precipitation profiles, increasing the incidence and severity of drought. Drought is the single largest abiotic stress factor leading to reduced crop yields. Given the large share of water use in the agriculture sector and very low efficiency in this sector, selection and development of the new strategies to improve and optimise irrigation water use with significant savings is essential. The usage of Superabsorbent polymers (SAPs) is one of the strategies in this regard. This paper briefly mentions to the previous studies about the effects of SAPs on soils and plants, suitable usage rate of SAPs for improvement of soils, raising of WUE and amount of irrigation water saving in this field. The results showed that SAPs could store water and nutrients and release them in drought stress conditions in light soils. Therefore, an acceptable biologic and grain yield with less irrigation water depth could be achieved.

Keywords: Superabsorbent polymer, Irrigation interval, Deficit irrigation

INTRODUCTION

Many countries have inadequate water supplies to meet their current urban, environmental and agricultural needs. During the time of increased water scarcity, population and water demands continue to grow (Postel et al., 1996; Bouwer, 2002). Thus, the challenge is to grow enough food for 2 billion more people over the next 50 years while supplying growing urban and environmental needs for water (Gupta & Deshpande, 2004; Gordon et al., 2005). Some analysts have estimated that 60% of added food requirement will

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E-mail addresses:
davood_kh70@yahoo.com or dkhodadadi@iauahvaz.ac.ir
(D. Khodadadi Dehkordi)

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come from irrigation (Plusquellec, 2002). Raising food production to support the larger world population requires sustaining improved performance of irrigation (Oster & Wichelns, 2003; Rockstorm et al., 2007; Ward & Velazquez, 2008). Drought stress is the most important factor limiting plant growth in arid and semi-arid regions. One of the new methods used for managing water in soil is the use of superabsorbent materials as a storage tank to prevent water waste and increase irrigation efficiency (Khodadadi Dehkordi & Seyyedboveir, 2013d).

SUPERABSORBENT POLYMERS

Superabsorbent polymers (SAPs) have been established as a soil conditioner to reduce soil water loss and increase crop yield. They are hydrophilic networks that can absorb and retain 1000 times more water or aqueous solutions than their original size and weight (Sojka & Entry, 2000). Thus, the application of SAPs to soil may increase water-holding capacities and nutrient utilisation efficiency (Lentz & Sojka, 1994; Lentz et al., 1998) and reduce water loss (Al-Omran & Al-Harbi, 1997). SAPs are used in soil to create a water reserve near the rhizosphere zone (roots) and benefit agriculture (Zohuriaan-Mehr & Kabiri, 2008; Han et al., 2010). Due to water resource crisis, water-saving agriculture is essential for sustainable development of human societies. Furthermore, droughts are predicted to become increasingly severe due to climate change (Gornall et al., 2010). Superabsorbent hydrogels (SAHs) are moderately crosslinked 3-D hydrophilic network polymers that can absorb and conserve considerable amounts of aqueous fluid even under certain heat or pressure. Due to their unique properties that are superior to conventional absorbents, SAHs have found potential application in many fields such as agriculture (Karadağ et al., 2000; Liu et al., 2006; Puoci et al., 2008), hygiene products (Kosemund et al., 2009), wastewater treatment (Kaşgöz & Durmus, 2008; Kaşgöz et al., 2008; Wang et al., 2008), sealing materials (Vogt et al., 2005) and drug delivery system (Sadeghi & Hosseinzadeh, 2008). Currently, further extension of application domains of SAHs was limited because the practically available SAHs are mainly petroleum-based synthetic polymer with high production cost and poor environmental friendly properties (Kiatkamjornwong et al., 2002).

Hence, the development of multi-component Superabsorbents derived from natural polymer and eco-friendly additives becomes the subject of great interest due to their unique commercial and environmental advantages (Kurita 2001), and such materials have also been honoured as the material families of ‘‘in greening the 21st century materials world” (Ray & Bousmina, 2005). Thus far, many natural polymers such as starch (Lanthong et al., 2006; Li et al., 2007), cellulose (Suo et al., 2007), chitosan (Mahdavinia et al., 2004; Zhang et al., 2007b), guar gum (Wang & Wang 2009) and gelatin (Pourjavadi et al., 2007) have been utilised for fabricating multi-component Superabsorbents. It was concluded that the composition and preparation technologies of Superabsorbents are the dominant factors affecting the properties of SAHs (Wang & Wang, 2010). Many types of material have been used for preparing Superabsorbents. In addition, most traditional water absorbing materials are acrylic acid and acrylamide-based products, which possess poor degradability. About 90% of Superabsorbents are used in disposable products and most of them are disposed of by landfills or by incineration (Kiatkamjornwong et al., 2002). In addition, there will be an environmental problem with SAPs (Zhang et al., 2006; Zhang et al., 2007b). Meanwhile, it has low absorption rate under high concentration of electrolyte, undesirable water-keeping capacity and high cost (Wang & Liu, 2004). In order to solve those problems, considerable attention has been paid to the naturally available resources such as polysaccharides and inorganic clay mineral (Ray & Bousmina 2005; Li et al., 2007). It has good commercial and environmental values with the advantages of low cost, renewable and biodegradable polysaccharides for deriving Superabsorbents (Yoshimura et al., 2005; Pourjavadi & Mahdavinia, 2006). Recently, a series of new Superabsorbents characterised by eco-friendliness and biodegradability made from some natural materials such as starch, cellulose, chitosan (Farag & Al-Afaleq, 2002; Lanthong et al., 2006; Peng et al., 2008; Wu et al., 2008) were used to react through radical graft polymerisation with vinyl monomers and crosslinking agent (Ma et al., 2011). Teimouri and Sharifan (2013) evaluated the effects of two monovalent salts (NaCl and KCl) in different concentrations on hydrate and dehydrate of some SAPs including Aquasorb, Stockosorb, Clophony and A 200. The results showed that A 200 and Clophony had the most hydrate and dehydrate, respectively.

Superabsorbents minimise micronutrients from washing out to water tables and cause more efficient water consumption, reduction in irrigation costs and intervals by 50%, water stress and mechanical damages to transplants during transferring, in addition to providing plants with eventful moisture and nutrients (Abedi Koupai & Mesforoush, 2009) and improving plant viability, seed germination, ventilation and root development. Moreover, Superabsorbents can increase water holding capacity of light soils and keep this capability for about 2 to 4 years (Khoram-Del, 1997). Superabsorbents were introduced to the markets in early 1960s by the American company of Union Carbide (Dexter & Miyamoto 1959). The product absorbed water thirty times as much as its weight but did not last long and was sold to greenhouse retail markets. Soon it was determined that the product was unsuccessful in the market because of its low swell (high cost per unit of water held) and short life (Joao et al., 2007). Materials having the capacity to absorb water 20 times more than their weights are considered as a superabsorbent (Abedi Koupai & Sohrab 2006). Hydrogels are three-dimensional networks of SAPs swelling in aquatic environment. Due to their cross bonds, they tend to hold a part of solvent in their structure instead of dissolving. Their performance depends on their chemical properties such as molecular weight, formation condition, along with chemical composition of soil's solution or irrigation water (Abedi Koupai & Asadkazemi, 2006; Abedi Koupai et al., 2008). There are three types of hydrophilic polymers including natural (polysaccharide derivatives), semi artificial (cellulosic primitive derivatives) and artificial (Mikkelsen, 1999). Artificial polymers are used more than natural ones because they are more stable against environmental breaking down (Peterson, 2002). Meanwhile, SAPs do not threat human life and environment (Boatright et al., 1997; Shooshtarian et al., 2011). A famous SAP in Iran is in title of Super AB A 200 is made by Rahab Resin, licensed under the Polymer and Petrochemical Institute of Iran. This superabsorbent is tripolymer of acrylamide, acrylic acid and acrylate potassium, as shown in Figure 1 (Khodadadi Dehkordi et al., 2013e).

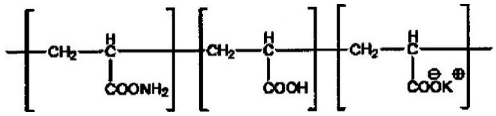

Figure 1. Chemical structure of Super AB A 200 SAP

THE EFFECTS OF SUPERABSORBENT POLYMERS ON SOIL

Since SAP can ease the burden of water shortage, proper use is helpful in arid and semiarid areas (Bakass et al., 2002; Zohuriaan-Mehr & Kabiri, 2008; Han et al., 2010). It has positive effect on water retention on various types of soils that can improve the physical properties of soil; these include increasing their water-holding capacity and nutrient retention of soil, delaying the time to reach permanent wilting point and prolonging plant survival under water stress (Huttermann et al., 1999; Oscroft et al., 2000; Viero et al., 2002; Abedi Koupai & Asadkazemi, 2006; Orikiriza et al., 2009). Yang et al. (2014) used SAPs as for water retention to improve the utilisation of water resources on rocky slopes eco-engineering. This superabsorbent polymer was provided by SIDA Co., Beijing, China. In this study, SAPs were used in three levels of 0.15%, 0.3% and 0.45% and mixed with sandy loam soil. The study was aimed to evaluate the saturated water content, evaporation rate and water holding capability of SAP treated soils, determine seed germination rate and plant survivals in soil with SAP by absorbing and spraying experiments. The addition of SAP to the sandy loam soil resulted in a significant increase of the soil water retention compared to the controls. In addition, seed germination was significantly higher in SAP amended soil than in the soil without SAP, whereas survival times of grass and woody were prolonged under water stress. In specific, 0.30% SAP treatment was the optimum selection for sandy loam soil improvement on steep rocky slopes. These studies indicated that SAP with good water retention properties was very effective in enhancing water uptake and utilisation of water for plants growth, and could be expected to have wide potential applications in rocky slopes eco-engineering.

SAP has hydrophilic groups that are able to absorb and retain fluid and release the fluid later under certain conditions (Zhang et al., 2006). A polymer is categorised as a superabsorbent if its ability to absorb water is more than 100 times its original weight (Zhang et al., 2007a). Most SAPs available in the market have low biodegradability making them environmentally unfriendly in the long run. Therefore, extensive studies have been conducted to use natural based polymers, namely, starch and cellulose, for biodegradable SAPs (Nakason et al., 2010). In general, SAP is synthesised by grafting or grafting crosslinking copolymerisation. The monomers used in grafting copolymerisation include acrylic acid and acrylamide (Li et al., 2007; Teli & Waghmare 2009), while N,N-methylene-bisacrylamide (MBA), trimethyl propane triacrylate and 1,4-butadienol dimethacrylate are used as crosslinkers (Swantomo et al., 2008). Commonly used initiators are persulfate salts, hydrogen peroxide (Moad & Solomon, 2006) and cerium salts (Al et al., 2008). Mas'ud et al. (2013) studied on increasing the benefits of cassava waste pulp by converting it into a superabsorbent. This conversion was carried out by a graft copolymerisation of cassava waste pulp using acrylamide, ammonium persulfate and N,N′-methylene-bisacrylamide as a monomer, an initiator and a crosslinker, respectively. The results showed that cassava waste pulp had a great potential to be used as a superabsorbent, which could give benefit to cassava.

In specific, SAPs improve water penetration rate, structure and texture of soil (Helalia & Letey, 1988; Helalia & Letey, 1989), soil-water retention (Tayel & El-Hady, 1981), soil infiltration and aeration, size and number of aggregates, water tension, available water (Abedi Koupai et al., 2008), soil crispiness (Azzam, 1980) and facilitate water management practices in soil (Shooshtarian et al., 2011). Abilities such as nutrient release and soil nitrification (El-Hady et al., 1981), increase in nutrient absorption, osmotic moisture of soil and decrease in transplanting stresses cause improvement in plant growth reaction (Hadas & Russo, 1974) and increase in yield and reduction in growth and production costs of plant. By absorbing hundred times of its origin weight, superabsorbent can be used as a cultural medium itself or can even be used alone as a rooting medium. Furthermore, it reduces impact pressure in turfs, usage of pesticide (i.e., herbicides, fungicides), absorbs soluble fertilizer and releases it in time, other than improving drainage when used as a soil amendment. In some cases, overuse of hydrogel can cause reverse results because it reduces soil air, followed by filling vacant spaces and gel swelling. There are many reports of no or low effect of gels in overused application in terms of plant growth indices. The main reason, as mentioned, is linked with occupation of numerous vacant spaces of soil leading to severe reduction in soil ventilation (Abedi Koupai & Mesforoush, 2009). In the report, it was illustrated that usage of high levels of superabsorbent in cultural medium caused reductions in soil porosity and air volume and could end up reducing plant growth rate as well. Thus, there is limitation in term of using SAPs levels (Woodhouse & Johnson, 1991; Shooshtarian et al.*,* 2011). Moradi and Azarpoor (2011) reported that superabsorbent could increase water-holding capacity of soil, infiltration, cation exchange capacity and reduce water consumption. Meanwhile, Tabatabaei and Heidari (2011) evaluated the effects of SAP (Stockosorb) on wetting front dimensions and irrigation intervals. Superabsorbent treatments were found to contain S_0, S_1 and S_2 equal to 0, 5 and 10 gr m^{-2}, respectively, and soil texture was sandy loam. The results showed that increasing superabsorbent amounts could cause the length of wetting front to decrease and its width to increase. In addition, after exceeding 24 hours of irrigation time, soil moisture of S_2 treatment was 46% more than S_0 treatment. Taheri-Sodejani et al. (2015) evaluated the using natural zeolite for contamination reduction of agricultural soil irrigated with treated urban wastewater. In this study, the effects of application method, dosage and particle size of natural zeolite were studied on EC, pH, BOD_5, Na^+, $Ca^{2+}+Mg^{2+}$ and nitrate concentration of an urban wastewater by passing it through zeolite-added soil columns. The results showed that by adding zeolite to the soil column, the values of pH, EC and Na^+ of the column outlet were increased, while its $Ca^{2+}+Mg^{2+}$, nitrate concentrations, as well as the BOD_5, were decreased. The BOD_5 levels of the column effluent in the control, mixed and layered treated soils with zeolite were lower than the BOD_5 of used fresh wastewater by 38.42, 54.98, and 71.84%, respectively. However, the nitrate concentration of the column effluent in the control, mixed, and layered treated soil with zeolite were lower than the nitrate content of the fresh wastewater by 12.18, 32.19, and 54.90%, respectively. Finally, the results showed that the application of the natural zeolite into the soil in a layered treatment reduced the pollutant transferred to the soil-depth more effectively and this consequently improved the quality of drainage water. Haghighat-Talab and Behbahani (2006) evaluated optimising model of water consumption in hydroponic greenhouses using *PR3005A* SAP. The results showed that the use of SAP could increase water use efficiency to 44 percent per m^3 in hydroponic greenhouses. The polymers are effective in correcting aggregation, prohibiting capillary water soar, decreasing cumulative evaporation and improving growth and efficiency in vast range of plant species (Johnson & Veltkamp, 1985; Choudhary et al.*,* 1995; Al Omran et al.*,* 1997; Sivapalan, 2006). Al-Darby (1996) reported that by increasing the concentration of hydrogel (0, 0.2, 0.4 and 0.8% - Jalma), the amounts of available water and saturated electrical conductivity progressively increased and decreased, respectively. In addition, the results of that experiment also showed reduction in water infiltration and spreading. Finally, he recommended the 0.4% application of Jalma hydrogel and stated that adding this amount of hydrogel led to better improvement in hydraulical properties of sandy soils. This amount of superabsorbent reduced in deep penetration while simultaneously providing adequate amount of infiltration and water conservation. Dorraji et al. (2010) reported that increasing level of polymer resulted in reduction of soil electrical conductivity. They noticed that after 0.6% polymer application in sandy, loam and clay soil, electrical conductivity declined by 15.3, 20 and 16.9%, respectively, compared to the control. Reduction in electrical conductivity is due to the ability of hydro gels to absorb and conserve a great deal of water and physiological solutions in themselves. Great amount of water causes a decrement in the concentration of salt and it leads to electrical conductivity reduction (Ramezani et al., 2005). It was concluded that in a soil type with loamy clay texture, the application of 0.4% polymer (Stuckosorob) increased survival percentage more than 0.2% with a significant difference compared to the control in *Pinus halepensis* (Huttermann et al., 1999). In the same experiment, when plants were stressed, the evapotranspiration rate was 90%; however, using 0.4% of that material reduced it by 50%. In fact, the polymer could reduce stress in plants. The survival percentage after the last irrigation increased from 49 to 82 days (Huttermann et al., 1999). In this study, the amount of plant growth in the control treatment was 43% less than that of 0.04% treatment. Karimi et al. (2008) stated that applying SAP of Igita caused some changes in the percentages of solid, gas and liquid phases in soil. In the pre-planting stage of their experiment, volume increment was between 10 and 40%, 5 to 32% and 9 to 37% in clay, loamy and sandy soils, respectively.

Montazer (2008) evaluated the effects of SAP (Stockosorb) on flow advance time and soil infiltration parameters in Furrow irrigation. Superabsorbent treatments were containing S_0, S_1, S_2 and S_3 equal to 0, 5, 7 and 9 gr m^{-2}, respectively. The result showed that adding Superabsorbent to Furrows increased flow advance time and soil infiltration. In particular, the soil infiltration in S_3 treatment was more than that of the S_0 treatment about 67%. Banej Shafie et al. (2006) evaluated the effect of SAP (Super AB A 200) on the moisture characteristics of sandy soils. The results showed that when a mixture of sand and SAP was provided in a way that 0.2 to 1.0 percent (w w^{-1}) of the mixture was polymer, the condition of water in the mixture would be similar to clay soil. When the amount of polymer reached 1%, the condition would be tougher than the previous one. In other words, the polymer caused more absorption of water in sand. In blown sand, the stored water was kept in the soil by a suction that was higher the suction in clay. Therefore, in order to increase the capacity of plant available water in blown sand and irrigation interval of the planted seedlings for afforestation in dry areas, adding polymer to the blown sand would result in undesirable conditions. Furthermore, using polymers increases the cost of operation. They are unsustainable materials that may have some other disadvantages. Results of this experiment suggest that usage of clay, instead of polymer and blown sands, would create better conditions.

Dashtbozorg et al. (2013) evaluated the effects of different sizes of SAP (Taravat A 200) on water retention capacity in two different soils. In this study, there were seven treatments of water absorbent materials including control (without the water absorbent material) and Taravat A 200 SAP in six sizes (0.21-0.25, 0.25-0.5, 0.5-1, 1-2, 2-3.4 and 3.4-4.75 mm), and each of them was used in the form of 2g per kg soil. Then, soil water content was measured for each treatment at the suctions of 0, 0.1, 0.3, 0.5, 1, 3, 5 and 15 bar and the soil moisture curves were plotted separately. The results showed that there was a significant difference between the treatments and two soil textures in various suctions and the interaction of these factors was at the level of 1%. Also, it was observed that SAP with the size of 1-2 mm resulted in an increase in the soil water holding capacity significantly compared with other treatments, especially in the light soil texture. In another experiment, Nadler (1993) observed that using polyacril amid increased water holding capacity in sandy and loamy soils but it had less effect in clay. As for the available moisture, the best results gained from the applications of PR3005A polymer (4 and 8 gKg^{-1}) and in loamy soils. The moisture amount in this situation was increased by 2 to 4 times, respectively (Ghaiour, 2000). Sivapalan (2006) stated that the remaining water in sandy soil was equal to 23% and 95% with the application of polymer 0.03 and 0.07% of its weight, respectively.

It is demonstrated that residual water amount in soil volume becomes more when it blends with Superabsorbent material (Elliot, 1992; Shim et al., 2008). The major factor is related to prohibiting from water subsidence. It is estimated that the additional water causes an increment in the frequency of irrigation in plants (Wang & Gregg, 1990; Mousavinia & Atapoor, 2006). Karimi et al. (2008) reported that utilising the Igita absorbent in soil increased water holding capacity and available water in soil and thereafter, the water intervals also increased. Increases in water intervals in clay soils were about 30 to 130%, 60 to 120% in loamy soil and 150 to 300% in sandy soil. The saved water quantity was 30, 40 and 70% in clay, loam and sandy soils, respectively. Abedi Koupai and Sohrab (2006) conducted an experiment to evaluate water holding capacity and water potential of three kinds of soils; they concluded that on the whole, the application of PR3005A at 6 to 8 gKg^{-1} increased the amount of available moisture by 1.5 to 3 times, respectively. In relation to increment in porosity, the effect of polymer was more outstanding in sandy soil because of more swelling grade, and this caused capillary porosity for about four folds compared to the control samples and decrement in aerial priority. In this experiment, the effects of polymer on irrigation intervals was estimated about 2 to 3 times compared to the control and it emphasised on decreasing costs and efficient water consumption. Ramezanifar et al. (2011) evaluated the effects of SAP (Taravat A 200) on the moisture curve of two different soils. In this study, two different soil textures including light and medium textures and five levels of SAP [S_0, S_1, S_2, S_3 and S_4, equal to 0 (control), 2, 4, 6 and 8 gr kg^{-1}, respectively] were considered. The results showed that SAP could increase soil moisture content. In every soil, increasing SAP levels contributed to increases in volumetric water content of soils, whereas the most effect was related to the S_4 treatment in light soil texture.

Haghshenas-Gorgabi and Beigi-Harchegani (2010) evaluated the effects of zeolite on water holding capacity in sandy and sandy loam soils. In this study, there were four levels of zeolite (0, 2, 5 and 8 percent) and soil moisture was determined at 0 to -15000 cm. The results showed that the operation of zeolite in sandy soil was better than sandy loam. Besides, adding 8% of zeolite in sandy soil increased some moisture parameters including field capacity from 11% to 13%, available water (1.5 times), residual moisture (2%) and saturated degree (6%). Sharifan et al. (2013) evaluated the effects of SAP (Taravat A 200) on the infiltration equation parameters (Kostiakov-Lewis) through the advance time calculated. In this research, there were four levels of SAP (0, 7, 11, 16 gr m^{-2}). The results indicated that by adding polymers increased advance time and soil cumulative infiltration. Seyed-Doraji et al. (2010) evaluated the effects of different levels of SAP (Taravat A 200) on water holding capacity and the porosity of soils with different salinities and textures. In this research, the polymers were added to different soil textures (sand, loam and clay) at the levels of 0, 0.2, 0.4 and 0.6% w w^{-1} and the salinity of the soils was adjusted at the levels of 0, 4 and 8 dS m^{-1}. The application of 0.6% w w^{-1} polymer at the lowest salinity level increased available water content by 2.20 and 1.20 times greater than the controls in sandy and loamy soils, respectively. Thus, the application of polymers to soil, especially in the sandy soil may increase water-holding capacity and decrease salinity, but it may help improve irrigation projects in arid and semi-arid areas.

Sarafrazi et al. (2011) evaluated the effects of SAP (Acryl amid potassium) on soil volumetric water content and grass water potential. In this study, the experiment was conducted in a randomised completed block design in four levels of polymers including 0 (control), 3, 6, 12 and 24 gr m^{-2} with three replications. The results showed that by increasing the SAP levels, soil volumetric water content also increased. In addition, consumed water was saved up to 75% in the SAP treatments in comparison with the control treatment. Meanwhile, Habibollahi and Hooshmand (2012) evaluated the effects of hydrophilic polymer on wetting dimensions, under drip irrigation. Their study investigated the effects of SAP (Taravat A 200) on vertical wetting depth under drip irrigation, including the four treatments (control (0), 0.1, 0.2, and 0.3 wt%). The investigation showed that the use of drip irrigation with SAP for 4 litres per hour discharge in loam soil, the soil wetting front penetration depth was reduced, while water accumulation in the surface layer (layer modified by the

SAP) increased. Pajuohesh et al. (2008) evaluated the effects of SAP on runoff volume in slopes and various intensities of rainfall. In their study, the main treatment was the three dominant slopes (10, 20, 30 percent), accessory treatments involved five levels of SAP (0, 20, 40, 60, 80 kg ha^{-1}) and three levels of various rainfall intensities were 25, 30, 40 mm hr^{-1}. The results showed that the SAP treatments of various rainfall intensities in comparison with control plate had significant effects in decreasing the output runoff volume to 5 level percent. Dashti et al. (2013) evaluated the effects of synthetic and natural Superabsorbent on nitrate movement in sandy soil. In their study, the treatments consisted of control and superabsorbent. The superabsorbents were synthetic ones (2 gr kg^{-1}) and natural ones (15 gr kg^{-1}). For this purpose, 9 pots were prepared and filled with sandy soil texture. Then, the amount of nitrate was measured by using a spectrophotometer in different values of porous volume (0.1, 0.3, 0.5, 0.7,1, 1.3, 1.7, 1.9, 2 and 2.5). The results showed that at the first stage of leaching, the natural Superabsorbent (manure) was more effective than the synthetic one. However, as the leaching continued, the synthetic superabsorbent absorbed more nitrate compared to natural one. The greatest effect of synthetic superabsorbent was seen at points 0.3 and 0.5 of porous volume and as the leaching was carried on, its effect on absorbing nitrate diminished. The largest effect of manure was obtained at points 2 and 2.5 of porous volume. Han et al. (2010) evaluated the porosity change model for watered SAP (Acrylate sodium co-polymers (ASC) treated soil. The study was aimed to evaluate the bulk density curve of watered SAP-treated soil and construct and test the model for porosity change of watered SAP-treated soil. The results showed that the application of SAP reduced soil bulk density, improved soil permeability and caused soil swelling.

Bai et al. (2010) evaluated the effect of SAPs on soil moisture, bulk density, pH, electrical conductivity (EC) and available P and K after different wetting and drying cycles. Four types of SAPs, labelled as BF, JP, BJ and WT with organic macromolecules, were mixed with sandy soils to give the concentrations of 0%, 0.05%, 0.1%, 0.2% and 0.3%, with the aim to determining water retention and soil properties after amendment with SAPs. Soil moisture increased by 6.2–32.8% with SAP application, while soil bulk density was reduced by 5.5–9.4% relative to the control, especially with a moderate water deficit when the relative soil moisture contents were about 40–50%. The largest increase in soil moisture and the greatest reduction in bulk density resulted from the WT treatment. The effects of SAPs on soil pH and EC were contrary. Soil available P increased slightly while available K significantly decreased, except following the first wetting and drying cycle. Available K increased with drying, but the opposite effect was observed for available P. Particular SAPs (JP and WT) which seemed more suitable under alternating dry and wet conditions. The effects on soil-water retention and other soil properties varied according to the structure of SAP and soil moisture. Khodadadi Dehkordi et al. (2013a,b,c) performed some research on SAP (Super AB A 200). The results showed that quadratic function was optimum water-yield production function in deficit irrigation situation with the presence of SAP for corn. Besides, with the increase of SAP ratios in sandy soil, the unsaturated hydraulic conductivity decreased. However, with the increase of SAP ratios in sandy soil, the saturated hydraulic conductivity increased. Also, with the increase of SAP ratios in sandy soil, the marginal production index (MPI) and the value of marginal production (VMPI) of corn yield increased. In addition, the results showed that with the increase of SAP ratios, the average matric potential of corn root zone along the growth season, reduced significantly.

In many studies, it is confirmed that reduction or lack of positive effectiveness was due to dissolved salt in water or fertilisers (Taylor & Halfacre 1986; Lamont & O'Connel, 1987). Effect of saline water is reduction in their capability of water absorption and conservation. Akhter et al. (2004), in a comparison, evaluated effects of water type on the amount and rate of absorption, and reported that the maximum time for absorption with distilled water, tap water and saline water were 7, 4 and 12 hrs, respectively. Moreover, the amount of absorption in 1 hr was measured as 505, 212 and 140 gg^{-1}, respectively. Naderi and Farahani (2006) conducted an experiment on three gel types (Yellow, Aquasorb and White) properties, and estimated that using tap water instead of distilled water reduced swelling degree in three SAP from 290, 250 and 218 gg^{-1} to 160, 164 and 150 gg^{-1}, respectively. Reduced impact of polymers in saline is because of the absorption process in polymers occurring based on thermodynamic balance and the osmotic pressure differences between gel network and exterior solution are decreased by increasing the ionic power in saline solution. Accordingly, swelling in solution medium is declined with growing ionic power in saline solutions (Kabiri, 2002). In a study, the application of SAP in loamy-sandy soils of Kuwait was assessed in order to evaluate the establishment of *Conocarpus lancifolius*. Results showed that an increase in water salinity more than 2.5 dSm^{-1} causes reduction in polymer effectiveness, and plants irrigated with 5 dSm^{-1} used 42% less than that of with 1.6 dSm^{-1} (Bhat, 2009). There are large quantities of trace elements in polluted soils, particularly in mining regions, causing an interruption in plant growth and establishment (Walker et al*.,* 2004; Celemente et al*.,* 2006; PerezdeMora et al*.,* 2007). Regarding the fact that installing new green spaces in these regions has been in environmental organisations schedule of many countries, there is a need to find a way to overcome this limitation. One of these ways is treating polluted soils with hydrophilic polymers to have better establishment and growth (DeVarennes & Queda, 2005; Mendez et al*.,* 2007; Guiwei et al*.,* 2008). Naderi and Farahani (2006) estimated that the solute ions in water greatly decreased gel swell and water absorption, whereas the best amount of pH was reported as neutral. They also suggested that it is better to apply ionic gels as soil pH in Iran is above 7 in most regions, provided that they possess low quantity of bivalent cations. Wallace and Wallace (1986) estimated that, in general, the most favourable results associated with anionic polymers. In other studies, however, the size of particles effects on absorption rate was found between polymer size and growth of *Ardisia pusilla* (Shim et al*.,* 2008; Shooshtarian et al*.,* 2011).

THE EFFECT OF SUPERABSORBENT POLYMERS ON PLANT

The previous studies on SAPs have focused on their effects on particular soil physical and chemical properties (Nadler et al*.,* 1996; Zhang & Miller, 1996) such as pH, electrical conductivity (EC) and soil water content (Bai et al*.,* 2010) for soil erosion control and irrigation management (Sojka et al*.,* 1998) and the effects on plant growth and production (Busscher et al*.,* 2009; Islam et al*.,* 2011). However, a few studies have investigated the effects of SAPs on soil microorganisms and plant available water in the natural environment. Therefore, Li et al*.* (2014) evaluated two types of SAPs [Jaguar C (JC) and Jaguar S (JS)] applied at 200 kg ha^{-1} by bulk and spraying treatments in a field trial to investigate their effects on winter wheat growth, physical properties of the soils, as well as microbial abundance and activity. It was found that addition of SAPs promoted the formation of macro soil aggregates (particle size >0.25 mm) and soil bacterial abundance under winter wheat cultivation. SAPs also significantly increased soil water content (SWC) and soil maximum hygroscopic moisture (SMHM) in the booting and filling stages but had no effects on the soil available water-holding capacity (AWC) compared with the control in the filling stage. The effects of SAPs were found to depend on the application strategy as only the bulk JC treatment improved the wheat yield, soil microbial biomass carbon (MBC) and soil microbial respiration (SMR). The results showed that the application of SAPs did not lead to detectable adverse effects on the soil microbial community and might even enhance soil microbial activity. Various applications of SAPs and active fields of applied research works on SAPs have been made. It was first applied in the agricultural production of corn and soybean, as well as seedling transplanting. Fanta et al*.* (1971) found that SAP contributed to water saving and yield enhancement. Later, SAP is also used in many areas such as pharmaceuticals, food packaging, paper production, the agricultural and horticultural industry, oil drilling, etc. (Wang et al*.,* 1998, Wang et al*.,* 2000a; Wang et al*.,* 2000b; Li et al*.,* 2004; Han et al*.,* 2010). In the agriculture and horticultural industry, the application of SAP is in the form of seed additives, seed coatings, root dips and so on (Zohuriaan-Mehr & Kabiri 2008). Many studies, in general, have indicated that SAPs cause improvement in plant growth by increasing water holding capacity in soil (Boatright et al*.,* 1997; Khalilpour, 2001; De Varennes & Queda, 2005) and delaying duration to wilting point in drought stress (Gehring & Lewis, 1980). Water conserving by gels creates a buffered environment which is effective in short term drought tensions and can reduce losses in the establishment phase of some plant species (Johnson & Leah 1990). Water consumption efficiency and dry matter production respond positively to Superabsorbent existence in soil (Woodhouse & Johnson, 1991; Shooshtarian et al*.,* 2011). Figure 2 shows the SAP of super AB A200 around plant root.

Figure 2. Super AB A200 SAP around plant root

Fazeli-Rostampoor et al. (2011) reported that drought stress and application of SAP (Taravat A 200) had significant effect on corn grain yield and water use efficiency (WUE). In this study, 3 different depths of irrigation were considered as the main treatments I_1, I_2, I_3 as 100, 70 and 40 percent of water requirement of plants respectively, whereas different levels of SAP were used as the secondary treatments (S_0, S_1, S_2 and S_3, equal to 0 (control), 35, 75 and 105 kg ha^{-1} respectively). The most corn grain yield and WUE were related to I_1 and S_3 treatments and the least of them were related to I_3 and S_0 treatments. Zangooei-Nasab et al. (2012a) reported that applying SAP (Stockosorb) had significant effect on plant height, dry weight of aerial organs, root dry weight and root length of Saxaul plant. In this study, three different irrigation intervals including I_1, I_2 and I_3 were considered as daily, three-day and five-day respectively and different levels of SAP including S_0, S_1, S_2 and S_3, equal to 0 (control), 0.1, 0.2, 0.3 and 0.4 weight percent, respectively. The most effect of SAP was related to 0.4% treatment that had not any significant difference with 0.3% treatment and the most effect of irrigation interval was related to the three-day treatment. Abedi Koupai and Mesforoush (2009) evaluated the effects of SAP (Super AB A 200) on the yield performance, growth indices (length of shoot), water use efficiency, and N, K, Fe and Zn uptake of a nursery plant (*Cucumis sativus* var. Gavrish). The greenhouse trial was conducted using factorial experiment with a completely randomised design layout in which the treatments were two soil textures (sandy and clay loam), three irrigation regimes consisting 50%, 75% and 100% ETc and the hydrogel treatments were containing 0, 4, 6 and 8 gr kg^{-1} hydrogel.

The results show that use of 4 g kg^{-1} SAP Super AB A200 in a light texture soil and without stress or 25% deficit irrigation is recommended to achieve the best marketable yield and desired water use efficiency. Banej Shafei (2000) investigated the effect of a SAP (Super AB A200) on increment of soil water accessibility, fertiliser efficiency, growth and establishment of *Panicum capillare*. The results illustrated that 0.3% application of this gel caused higher production of dry matter in three different soil textures (light, medium and heavy) and three irrigation intervals (4, 8 and 12 days) in all the treatments.

Karimi and Naderi (2007) evaluated the effects of different rates of a SAP (Vinyl alcohol acrylic acid) on dry matter yield (Y) and water use efficiency (WUE) of forage corn. A greenhouse experiment was carried out as a factorial complete randomised design with 18 treatments and 3 replicates. Six levels of SAP (0, 0.05, 0.1, 0.2, 0.3 and 0.4 dry basis percentage, S_0 to S_5) and three soils differing textures (clay, loamy and loamy sand, A_1 to A_3) were used. Forage corn was planted in the pots. The pots were irrigated based on 60% depletion of soil available water for the all treatments. Yield (Y), evapotranspiration (ET) and water use efficiency (WUE) were measured. The results indicated that the effects of soil, SAP and their interactions were significant (P<1%) on Y and WUE. Clay soil (A_1) had maximum Y, while WUE and loamy soil (A_2) and loamy sand soil (A_3) had minimum Y and WUE. There were significant differences in WUE between S_1 and the other rates. Meanwhile, S_5 and S_0 had maximum and minimum Y and WUE values, respectively. The results indicated that there was no significant difference between S_4 and S_5 treatments. Moreover, the application of SAP at five levels increased Y and WUE. In summary, the application of 0.05, 0.1 and 0.3 dry basis percentage of SAP, in clay, loamy and loamy sand soils, caused maximum Y and WUE, respectively.

Ahrar et al. (2009) evaluated the effect of hydrogel amendment and *Cucurbita pepo*. Rootstock on hydroponically cultured greenhouse cucumber. Results showed that incorporating hydrogel into media could improve media physical properties and increase its water holding capacity. This condition could also decrease leaching fraction and increase yield and water/ fertiliser use efficiency. Moghimi et al. (2011) evaluated the effects of perlite different amounts on grain yield and water use efficiency in winter wheat (Zarrin cultivar). A field experiment using completely randomised block design with seven treatments (P_0, P_1, P_2, P_3, P_4, P_5 and P_6) including: zero (reference), 75, 150, 300, 600, 1200 and 2400 kg.ha^{-1} with four replicates was conducted. Results of statistical analysis showed that the use of rates in all the treatments significantly increased crop . The results showed that adding perlite to the soil, grain yield and biological yield of wheat increased up to 39.9 and 31.5 percent, respectively, which statistically is significant at one percent level. Also, there was a significant difference between grain proteins of treatments at five percent level. The results also showed that in the treatment with application of 2400 kg.ha^{-1} perlite, water use efficiency increased by up to 40.12 percent. The results of a study to evaluate the effects of 5 levels of SAP on turf grass in Tehran (Iran) illustrated that the substance caused increases in colour intensity, density and coverage area but a reduction was found in the wilting rate. Furthermore, it is stated that the most efficient amount was 100 gr per 1 m^2 (Khushnevis, 2006). According to the estimated results of Evaporation Pan in part of Tehran (Iran), each 1 m^2 of turf grass requires around 14 to 18 litres of water in warm seasons daily. Providing this amount of water is rather difficult. Using 100 g of SAP in the mentioned area can reduce water consumption by 50% (Ataei & Ghorbani, 2001). Another study on turf grass indicated that 8 g application of a SAP per 1 Kg of soil enhanced the available moisture up to 4.2, 1.8 and 2.2 times in sandy-loamy, clay and loamy soils respectively in a suction range of 0.3 and 15 bar (Mousavinia & Atapoor, 2006). Al Humaid and Moftah (2007) reported that application of K400 Stockosorb polymer in 0.4 to 0.6% of weight caused water potential of Buttonwood (*Conocarpus erectus* L.) seedlings to increase significantly in dry region of Saudi Arabia. These seedlings survived three times more than those controlled under drought stress. They also expressed that root and shoot growths were significantly increased using hydrogels. Abedi Koupai and Asadkazemi (2006) illustrated that applying 4 and 6g Kg^{-1} of SAP (Super AB A 200) decreased one third of Arizona cypress (*Cupressus arizonica* Greene.) water demand in comparison to the controls. Lawrence et al. (2009) claimed that under drought stress in green house, amending soil with SAP (Polyacrylate) (0.2 and 0.4% in weight) caused biomass increment in 9 ornamental tress species. They also announced that adding this material to the soils held their moisture in field capacity range and caused an increase in water consumption efficiency, which is used in photosynthesis. Another experiment was conducted to determine the effects of two kinds of SAPs (Stockosorb and Luquasorb) on *Populus popularis* grown under drought and saline tension. It was observed that 0.5% application of two kinds of polymer in cultural medium could reduce the plant growth and leaf gas exchanges prevention rate induced by mentioned stresses (Shi et al*.,* 2010). Hutterman et al. (1999) reported that SAP (Stockosorb K 400, a highly cross-linked polyacrylamide with about 40% of the amide group hydrolysed to carboxylic groups) caused improvement in the shoot and root performance of *Pinus halepensi*s Mill under dry condition.

Sarvas et al. (2007) in an experiment on *Pinussylvestris* L. seedlings observed that by overusing SAP (Stockosorb) in soil, plants were more likely to be exposed to Fusarium diseases and mostly perished. They suggested that investigations needed to be carried out to find out the most suitable amount of hydrogel to be used in different situations and for plant species. Results of another study showed that adding polymer up to 0.3% had positive effect; in concentrations over 0.4%, however, the effects were reversed (Al Harbi et al., 1999). Fry and Butler (1989) concluded that in order to reduce drought stress in Tall fescue (*Festuca arundinacea*) in sandy soil, the amount of SAP has to be 80 folds compared to the recommended amount. Khadem et al. (2010) evaluated the effects of animal manure and SAP (Taravat A 200) on leaf relative water content, cell membrane stability and leaf chlorophyll content (SPAD) of corn under drought stress. In their research, water stress was applied by three different irrigation intervals (irrigation after 70, 105 and 140 mm evaporation of basin class A) which were allocated to main plots. A combination of six levels of animal manure and SAP allocated to subplots are as follows: S_1: control, S_2: 100% animal manure (40 t ha^{-1}), S_3: 100% SAP (200 kg ha^{-1}), S_4: 50% animal manure+50% SAP, S_5: 35% animal manure+65% SAP, S_6: 65% animal manure+35% SAP. The results showed that the highest leaf relative water content (RWC) was obtained with 100% SAP (200 kg ha^{-1}), and it was reduced by increasing drought stress. Meanwhile, cell membrane stability (CMS) increased with increasing drought stress and decreased by using animal manure and SAP. Leaf chlorophyll index (SPAD values) increased in response to drought stress and by using different combinations of animal manure and SAP. 1000-seed weight and grain yield was decreased by drought stress. Grain yield decreased by yield components reduction, especially 1000-seed weight due to drought stress. 1000-seed weight and grain and biological yield increased by using animal manure and SAP together as the maximum yield grain was obtained by using 65% animal manure and 35% SAP.

Rahmani et al. (2010) evaluated the effects of different levels of water deficiency stress and SAP (Super AB A 200) on yield, antioxidant enzymes activity and cell membrane stability in mustard. The treatments included five levels of water deficiency stress (irrigation after 80 mm evaporation from class A evaporation container, cut irrigation from booting stage, flowering stage, silicling stage and grain filling stage) and three levels of applying SAP (amount of 0, 5 and 7 weight percentage). Results showed that the effects of water deficiency stress and SAP were significant. The mutual impacts of water deficiency stress and SAP were not significant for any treatments. Normal irrigation and usage of concentration of 7%, level 3, of SAP with mean of 5.803 and 25.78 t h^{-1} showed the most seed and biological performance. Cut irrigation from booting stage without applying SAP with mean of 206.1 and 5231 ($mg.protein^{-1}$) showed the most activity of catalase and super oxide dismutase and with mean of 2683 Ls cm^{-1} showed the least cell membrane stability. Ghasemi and Khoshkhui (2008) evaluated the effects of SAP (Super AB A 200) on irrigation interval, growth and development of Chrysanthemum. In their study, four different irrigation intervals (I_1, I_2, I_3 and I_4 as two-day, three-day, four-day and five-day, respectively) and different levels of SAP [S_0, S_1, S_2, S_3, S_4 and S_5, equal to 0 (control), 0.2, 0.4, 0.6, 0.8 and 1 weight percent, respectively] were taken into consideration. The results showed that SAP had significant effects on the number and diameter of flowers, dry and fresh weight of flowers, branches and roots, number of leaves, leaves area, as well as number of branches and plant length in drought stress conditions. The best treatment was I_1S_4. Jalili et al. (2011a) evaluated the effects of SAP (Tarawat A 200) and irrigation period on generative growth of Rosa bushes. In their research, randomised complete block design in natural field for two factors (SAP in 4 levels including 0, 40, 90 and 140 gr and irrigation period in 4 levels [6, 10, 14 and 18 days]) was used with 3 replications. The findings showed significant impacts of SAP in increasing irrigation and various growth parameters in Rose. In qualitative parameters, 40 and 90 gr levels of SAP had a positive effects on number of main branch parameters; however, it had no significant effect on total number of branches and number of flowers. As for irrigation factor, 6 and 10 day levels in number of main branch and total number of branches parameters had a significant difference with that of other levels. Increasing irrigation periods and decreasing water availability for plants led to reduction in flowers.

Jalili et al. (2011b) evaluated the effects of SAP (Tarawat A200) and irrigation period on Almond seedling. Their research used randomised complete block design in natural field for two factors (SAP in 4 levels including 0, 60, 100 and 125 gr in 100 kg soil and irrigation period in 4 levels including 7, 12, 18 and 24 days) with 3 replications. Results showed no significant difference between the treatments in the first year. In the second year, however, a significant difference was observed between the treatments in most of growth indices. Alami et al. (2011) evaluated the effects of SAP (Super AB A 200), Paclobutrazol and irrigation period on *Lolium perenne cv.* Barbal. For this purpose, they used randomised complete block design for three factors (SAP in 4 levels including 0, 3, 6 and 9 gr kg^{-1}, irrigation period in 3 levels including 2, 4 and 6 days and Paclobutrazol in 2 levels including 0 and coated grains by 30 mg l^{-1} Paclobutrazol) with 3 replications. The results showed that the best density achieved in 6 gr kg^{-1} SAP and two-day irrigation period. In an experiment, it was stated that *Conocarpus lancifolius*, in warm and dry climate of Kuwait, needed 50% less irrigation water when treated with Agrihope Superabsorbent in 0.4% of weight concentration. Furthermore, at that concentration, available water capacity increased from 7.29 (in control) to 18.75% (Bhat et al*.,* 2009). Although clay soil holds great deal of water, the available water for roots would be less than half. On the other hand, more than 90% of water absorbing by Superabsorbent is available to plant roots (Joao et al*.,* 2007). Abedi Koupai and Sohrab (2006) estimated that 2 to 8 g of hydrogel (Super AB A 200) per each 1 kg of soil increased the moisture quantity roughly 1 to 2.6 times respectively in comparison with the control. In an experiment to evaluate the effects of Aquasorb on irrigation of three species seedlings including *Atriplex canescens*, *Pinus Eldarica* and Populus euphratica, it was estimated that using 1% polymer three times higher than the control interval could have the same result as the control irrigation. In general, they reported that it is recommendable to use polymer in planting time for the mentioned species to reduce irrigation rate and interval with proper survival percentage (Poormeidany & Khakdaman, 2006). Sheikhmoradi et al. (2011) evaluated the effects of SAP (Super AB A 200) and irrigation period on some qualitative characteristics of sport grass. In this study, it was considered four different irrigation intervals [I_1, I_2, I_3 and I_4 as one-day, two-day, four-day and six-day, respectively] and four levels of SAP [S_0, S_1, S_2 and S_3, equal to 0 (control), 20, 25 and 30 gr $m^{-2,}$ respectively]. The results showed that applying SAP was significant (at 1% level) in some growth indices including shoot height, total chlorophyll and plant density. The best treatment was I_2S_3. Banej Shafie et al. (2012) evaluated the effects of SAP (Manufactured by Flowergel co., of Netherlands) application and irrigation period on the growth of pistachio seedlings. In their study, the treatments applied were SAP in 3 levels (0, 50 and 100 gr), irrigation amount in 2 levels (5 and 10 lit) and irrigation period in 3 levels (10, 20 and 30 days). The results showed that using 50 gr SAP halved irrigation amount (5 lit) in 10-day period intervals. Using 100 gr SAP with 10 lit water increased period of irrigation from 10 to 20 days. In addition, applying SAP increased the height growth and diameter at collar growth compared to controls. It was concluded that SAP diminished water consumption and irrigation frequency by 50%. Nikoorazm et al. (2009) evaluated the effects of applying SAP (Tarawat A 200), irrigation regimes and polymer usage style on lettuce growth. In their study, four levels of SAP (0, 20, 40 and 60 gr per plant), four irrigation regimes (5, 8, 11 and 14 days) and polymer usage style (layering and mixed whit soil) were performed on growth lettuce under greenhouse conditions. The results showed no significant differences between the irrigation regimes on fresh and dry weight. Moreover, the high levels of SAP (60 gr per plant) increased fresh and dry weight compared to the control (without polymer) and the lowest level of polymer (20 per plant). These results indicated that high amounts of SAP had positive effects on growth lettuce.

Abdi and Hedayat (2009) reported that adding 2 to 5% SAP (Super AB A 200) could increase length and diameter of branches, petiole length and leaf area of Lycopersicom esculentum Mill and Capsicum annuum L. Bordbar et al. (2011) evaluated the effects of SAP (Super AB A 200) and irrigation period on yield and yield components of sunflower. In this study, three levels of irrigation period (12, 16 and 20 days) were used as main factor and four levels of SAP (Tarawat A 200) (0, 30, 60 and 90 kg ha^{-1}) as the sub factor. The results showed that application of 90 kg ha^{-1} of SAP with 12 days irrigation period caused the highest yield, whereas the control treatment with 20 days irrigation period had the lowest yield. Generally, by increasing the amount of SAP and with shorter irrigation period, the yield and yield components were significantly increased. Zangooei-Nasab et al. (2012b) evaluated the effects of SAP (Stockosorb) and irrigation period on some physical characteristics of soil and growth indices of Atriplex plant. In this study, three different irrigation intervals (I_1, I_2 and I_3 as daily, three-day and five-day, respectively) and five levels of SAP (S_0, S_1, S_2, S_3 and S_4, equal to 0 (control), 0.1, 0.2, 0.3 and 0.4 weight percent, respectively) were considered. The results showed that SAP had significant effect (at 5% level) on some growth indices including plant height, dry and fresh weight of aerial organs, dry and fresh weight of root and root length. The best treatment was I_2S_4. Besides, SAP caused significant increase in soil saturated degree and available water content and decrease in bulk density and EC.

Yadollahi et al. (2012) evaluated the effects of SAP (Stockosorb) and organic matters in retention of water and establishment of Almond gardens in rainfed conditions. The results showed that SAP and organic matters could increase soil relative moisture significantly. This situation could increase growth indices of Almond seedlings. Razban and Pirzad (2011) evaluated the effects of varying amounts of SAP (Super AB A 200) under different irrigation regimes on growth and water deficit tolerance of German Chamomile. In their study, treatments included water deficit stress (irrigation after 50, 100, 150 and 200 mm evaporation from pan class A) and varying amounts of SAP (0, 60, 120, 180, 240 and 300 kg ha^{-1}). The results showed that the effect of SAP was non-significant in Capitulum yield, the numbers of Capitulum per plant, Capitulum diameter, Capitulum length, receptacle height, Capitulum weight and leaf soluble carbohydrates. In contrast, interaction effect between deficit irrigation and polymer was significant on biomass yield, chlorophyll a+b, total chlorophyll and proline. Yazdani et al. (2007) evaluated the effects of SAP (Tarawat A 200) on soybean yield and yield components. In their study, there were four levels of SAP (0, 75, 150 and 225 kg ha^{-1}) and three irrigation intervals (6, 8 and 10 days) on growth, yield and yield components of soybean. The results showed that the highest level of SAP (225 kg ha^{-1}) increased seed yield, 100-grain weight, number of pod per main branch, oil and protein yield and seed protein content in comparison with the control treatment and the lowest level of polymer (75 kg ha^{-1}). These results indicated that high amounts of SAP had positive effects on yield and yield components of soybean even under drought-stress conditions.

Keshavarz and Farahbakhsh (2012) evaluated the effects of Superabsorbent (zeolite) and drought stress on yield components of forage millet. In their study, there were three levels of Superabsorbent (0, 150 and 300 kg ha^{-1}) and four irrigation levels (40, 60, 80 and 100 percent of field capacity). The results showed that adding of Superabsorbent could increase dry and fresh weights, height and diameter of stem, node and claw number of forage millet. The most amount of growth indices was related to 300 kg ha^{-1} Superabsorbent treatment. Poorpasha et al. (2011) evaluated the effects of SAP (Super AB A 200) and Nitrogen fertilizer on yield and yield component of wheat. In their study, there were three levels of SAP (0, 100 and 200 kg ha^{-1}) and four levels of Nitrogen fertiliser application (0, 50 and 100 percent of fertiliser need). The results showed that by applying SAP, some indices (including fertile claw number, grain yield and harvest index) increased. Besides, the treatment with 200 kg ha^{-1} SAP achieved the most grain yield. By applying of 200 kg ha^{-1} of SAP and 100% of fertiliser need achieved the most fertile claw number and grain yield. Roostai et al. (2012) evaluated the effects of SAP (Super AB A 200) and animal manure ratios on the quantitative and qualitative characteristics of soybean under drought stress. In this study, the main factor was irrigation with 50, 100 and 150 mm (evaporation from class A pan) and sub-factor was (0) control, 40 t.ha^{-1} animal manure, 200 kg.ha^{-1} SAP, 50 percent SAP plus 50 percent animal manure, 65 percent SAP plus 35 percent animal manure and 35 percent SAP plus 65 percent animal manure. The results showed that pod number, grain number per plant, 1000-grain weight, grain, biological, protein and oil yield increased when SAP and animal manure were applied significantly. Finally, the combination of 35 percent SAP and 65 percent animal manure was the best treatment in this experiment. Allahyari et al. (2013) evaluated the effects of SAP (Aquasorb) application on yield and yield components of two chickpea cultivars under rainfed conditions. In this study, the experiment treatments included three levels of SAP (0, 150 and 300 gr m^{-2}) and two chickpea varieties (Jam and ILC482). The results showed that all the studied characteristics were affected by SAP. The highest grain yield (160.541 gr m^{-2}) obtained in Jam cultivar by applying 300 gr m^{-2} polymer and lowest grain yield (71.276 gr m^{-2}) obtained in ILC482 cultivar without polymer application. Finally, SAP application increased pod number in plant, 100-grain weight and biological yield compared to the control.

Islam et al. (2011) evaluated a water-saving SAP (Granular type) for minimising NO_3^- leaching from soil and optimising corn growth and yield. Thirty-six undisturbed soil lysimeters were installed in a field lysimeter facility in drought affected northern China to study the growth and yield characteristics of summer corn (*Zea mays* L.). The amount of NO_3^-leaching losses under different fertiliser (standard, medium or 75% and low, or 50% of conventional fertilization rate) and SAP [control (0); level-1 (15 kg ha^{-1}) and level-2 (30 kg ha^{-1})] treatments. The results showed that corn yield fell by 19.7% under medium and 37.7% under low fertilisation. The application of SAP increased yield significantly by 44.4% on level-1 and 80.3% on level-2, respectively. Similarly, plant height, leaf area, number of grains as well as protein, soluble sugar and starch contents in the grain also increased with SAP treatment. Application of SAP at 30 kg ha^{-1} plus half of conventional fertilisation could reduce maximum (64.1%)

nitrate leaching losses from soil. Rahimian and Hosieni-rad (2007) evaluated the effects of SAPs (Stockosorb and Super AB A 200) on yield and water use of tomato. The treatments were as 1- control (without polymers and irrigation with 7-day interval), 2- ten kg ha^{-1} Stockosorb and irrigation with 7-day interval, 3- thirty kg ha^{-1} Stockosorb and irrigation with 14-day interval, 4- fifty kg ha^{-1} Stockosorb and irrigation with 14-day interval, 5- seventy kg ha^{-1} Stockosorb and irrigation with 21-day interval, 6- ninety kg ha^{-1} Stockosorb and irrigation with 21-day interval, 7- ten kg ha^{-1} Super AB A200 and irrigation with 7-day interval, 8- thirty kg ha^{-1} Super AB A200 and irrigation with 14-day interval, 9- fifty kg ha^{-1} Super AB A200 and irrigation with 14-day interval, 10- seventy kg ha^{-1} Super AB A200 and irrigation with 21-day interval, 11- ninety kg ha^{-1} Super AB A200 and irrigation with 21-day interval. The results showed that there were significant differences (at 1% level) between the treatments. The best treatment was No.7 that yielded 45.3 ton ha^{-1} tomato that was 40% more than control yield. This was followed by treatment No.2 that yielded 40.3 ton ha^{-1} tomatoes, which was 28% more than control yield. Khodadadi Dehkordi and Seyyedboveir (2013d) evaluated the effects of drought stress and different levels of SAP (super AB A 200) and their effects on water use efficiency (WUE) and yield response factor (Ky). In their study, 3 different depths of irrigation were considered as the main treatments I_1, I_2, I_3 as 100, 75 and 50 percent of water requirement of plants respectively and different levels of SAP were used as the secondary treatment (S_0, S_1, S_2 and S_3, equal to 0 (control), 15, 30 and 45 gr m^{-2}, respectively). The results revealed that the effect of Superabsorbent treatments on biologic and grain yield of corn was significant at 1% level. Besides, the independent effect of irrigation and SAP treatments at 1% level and interaction between them at 1% level on WUE of corn were significant. I_1S_3 treatment had the most WUE amount (16.18 kg $ha.mm^{-1}$) and I_3S_0 treatment had the least WUE amount (6.48 kg $ha.mm^{-1}$). Figure 3 shows the manner of putting SAP in the ridges. In this manner, SAPs are put on the furrows at first, after that they are hilled up by ridges soil (Khodadadi Dehkordi & Seyyedboveir, 2013d).

Figure 3. Application of SAP in ridge and furrow system

CONCLUSION

The results showed that irrigation water depth was reduced by applying Superabsorbent in water restriction conditions. SAPs could remain in soil for 3 to 5 years and retain their capability. The results showed that the application of Superabsorbent in light soils with less irrigation water depth achieved more grain yield and biologic yield. This is due to the nutrients and water storage by Superabsorbent in light soils that created favourable conditions for plant growth. In addition, the results also showed that soil water-holding capacity in light soils could be increased with Superabsorbent. From the economic aspect, SAPs are costly in many countries. Thus, subsidy needs to be given to farmers to encourage them to use it. Therefore using SAPs can be regarded as profitable and if farmers use them in growing plants, it can help save water resources. In conclusion, applying SAPs could improve light soils characteristics and help cultivation in these soils, particularly in areas with limited water supplies and restricted nutrient conditions.

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